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Geographic Information System (GIS) modeling approach to determine the fastest delivery routes



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Abstract This study involves the adoption of the Geographic Information System (GIS) modeling approach to determine the quickest routes for fresh vegetable delivery. During transport, fresh vegetables mainly deteriorate on account of temperature and delivery time. Nonetheless, little attention has been directed to transportation issues in most areas within Kuala Lumpur. In addition, perishable food normally has a short shelf life, thus timely delivery significantly affects delivery costs. Therefore, selecting efficient routes would consequently reduce the total transportation costs. The regression model is applied in this study to determine the parameters that affect route selection with respect to the fastest delivery of fresh vegetables. For the purpose of this research, ArcGIS software with network analyst extension is adopted to solve the problem of complex networks. The final output of this research is a map of quickest routes with the best delivery times based on all variables. The variables tested from regression analysis are the most effective parameters to make the flow of road networks slower. The objective is to improve the delivery services by achieving the least drive time. The main findings of this research are that Land use such as residential area and population as variables are the effective parameters on drive time.

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1. Introduction

Enhancing delivery services of perishable goods such as fresh vegetables in large cities is a major concern. Such distribution issues are more critical for fresh vegetable producers, who are feeling impelled to find potential solutions. Factors including traffic density and mobility, especially in the context of large cities such as Kuala Lumpur, remain highly influential in determining total distribution costs. Moreover, delays in fresh vegetable delivery adversely affect trucking company profits. Delivery cost largely depends on the way distribution problems are solved, as these problems are vital vis-à-vis preserving the

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nutritional value of vegetables, which will in turn guarantee higher demand.

Due to the tropical climate of Southeast Asia, optimizing distribution planning systems, especially for perishable goods, is of utmost importance. Malaysia is a country with mostly invariable high temperatures throughout the year. Thus, the optimization of routing systems in Malaysia continues to draw extensive attention.

The Malaysian population has experienced the highest growth over the past decade (Sheng et al., 2008). However, little attention has been given to parking and transportation matters in most areas within cities in Malaysia (Tey, 2003). Keeping in view that private cars are now a much more convenient form of transportation than public transport. In the majority of regions within Kuala Lumpur, land use patterns reflect most respective areas (Ariffin and Zahari, 2013).

The most significant reason for applying network analysis and route planning to transportation is that businesses are interested in determining the best routes to minimize cost and time (Memon, 2005). The focus of this study is therefore on network analysis application for determining the quickest routes in terms of time, to deliver fresh vegetables to selected hypermarkets around Kuala Lumpur and Selangor.

Like an index model, a regression model can use overlay operations in a GIS to combine variables needed for the analysis (Chang, 2008). The regression model is applied in this study as well, and the variables are tested via this model. The most significant variables are taken into account in the model, and one that has not contributed any value to drive time is omitted from the analysis. In the final regression model process, a proper formula is identified as the variables demonstrate the most significant place in the context of this study.

The importance about GIS is that; GIS combines digital maps with traditional databases, and provides visual representations of information. Geographic Information Systems (GIS) offer spatial modeling options that accounts for the influence of various factors, such as distances between the main location of producing the fresh vegetables, market places and type of roads.

The traditions of GIS are strongly based on the maps, and even today it is common to introduce GIS through the ideas of representing of contents of maps in computer databases. GIS shows the real world objects on map and user friendly spatial tools to accomplish complex task. Geographic Information System is used to display, manipulate and analyze spatial (map) data. Spatial data are data that contain a reference to a place (Nayati, 2008).

The society is the best decision maker on Land Use. Land use can be changed based on society decisions whether to be a farmland or industrial or suitable for residential area (Ashraf et al. (2012).

GIS technology provides the capability of spatial data and network system for representation of real data in producing different kinds of maps.

The capability of the selected model is to solve the problem of finding the fastest routes between the distribution center and the hypermarkets as destinations. The focus of this study is on examining the significant parameters such as traffic density, drive time, population, land use, school zone for selecting the fastest delivery routes. Visual representation of the information via various maps is the new method for this kind of research to predict the fastest routes.

The objective is to improve the delivery services by achieving the least drive time to reach to the market places for keeping better quality of production as well as having higher demands.

The main objective of this research is to identify the effect that the most critical factors have on the selection of the fastest routes for fresh vegetable delivery in terms of time. As another objective, a GIS model is proposed to solve the distribution problem based on the variables derived from the GIS model. Visualization, as the outcome of this research, will help people approach problems in the dimensions of space and time and in the form of digital maps rather than dimensionally-restricted data tables and graphs (Han, 2001).

2. Literature review

The price of fossil fuel has been on the rise over the past decade. Vehicle fuel consumption is approximately 30% greater under heavy congestion conditions, especially during peak hours, with the result being longer delay time. A study was conducted on the effects of different levels of traffic on delay time to identify the ideal routes in static and dynamic traffic networks, with the parameters considered being drive time and fuel cost (Shokri et al., 2009).

Winyoopradist and Siangsuebchart (1999) developed a model on Network Analyst based on vehicle speed at different times of the day. In their work, the Network Analyst tool has the capability of calculating the shortest traveling time between two locations by specifying the starting time. Focus was on the speed patterns on some roads at different times of day and days of the week. Echols (2003) developed a GIS application to determine the quickest route between two destinations based on distance and travel time. Unfortunately, Echols (2003) did not consider land use as a variable for calculating efficient transportation routes.

To solve routing problems and find the most suitable paths for dispatching fresh produce, several methods have been applied. Although the GIS system provides calculations that result in visual solutions, which users can utilize to make prompt decisions. For example, Osvald and Stirn (2008) did research on the distribution of fresh vegetables, Belenguer et al. (2005) studied delivery routes for the meat industry, while Tarantilis and Kiranoudis (2001) analyzed the distribution of fresh milk. Incidentally, Tarantilis and Kiranoudis (2002) solved the fresh meat distribution problem by applying several algorithms to identify optimal sets of routes. The limitation of the mentioned research is that the author applied the mathematical equation instead of spatial data for finding the efficient routes. Moreover, the parameters that have an impact on traffic issues have not been considered.

The advantage of the GIS model is that it produces several maps while representing real route networks in order to reach markets in the quickest time possible. Moreover, the GIS application has a user-friendly interface that enables users to easily communicate and interact with other applications.

Chen et al. (2008) used GIS technology to determine optimal transportation routes and proposed a Geographic Information System model for nuclear waste transport route selection. The weighting method was applied in this process. The shortfalls of this study were that land use was not taken into consideration, and the average speed of vehicles was not

part of the estimation process of determining the final routes. Cairns (1998) concentrated on GIS aspects, while Akay et al. (2012) proposed a Geographic Information System model based on a decision support system to assist fireman. The GIS approach in Akay's research did not mitigate the routing problem.

Memon (2005) conducted a research on the application of GIS in the field of transportation. The objective of the thesis was to apply GIS to transportation to find optimal roads among sets of routes. The average speed of a vehicle was not considered for all road networks and the advantages of the GIS application are not apparent in this type of research.

In route planning systems based on GIS, Gohari (2010) developed a model to analyze the shortest paths and closest facilities. Gohari (2010) took into account several factors, such as the speed limit of a car in a road network. Sadeghi-Niaraki et al. (2011) examined road networks in the Geographic Information System for network analysis. The weakness with Sadeghi-Niaraki et al. (2011) model is that the spatial data (i.e. data obtained from road networks) are not incorporated into the calculation of optimal delivery service routes.

An application of ArcGIS Network Analyst tool for modeling route optimization was developed by Bhambulkar (2011) to identify best routing and has been applied to municipal waste collection. Sharifi et al. (2009) researched site selection of hazardous waste disposal using GIS technology for land use suitability, and presented a multi-criteria decision analysis with spatial data for the best selection of suitable sites for waste material landfills.

Applying the regression model in different fields of study has helped examine various parameters and variables, and test different methods of approaching the problem statement regarding finding the fastest routes. In this regard, Gkolias and Boile (2001) applied a GIS-based tool for distribution managers in order to estimate truck volumes on highway system sections.

The independent variables considered in the regression model are number of employees, sales volume, and number of establishments for different standard industrial classification (SIC) categories. With regard to regression model application in traffic management, a research analyzed the problem of optimal routes associated with transportation (Sofia et al., 2013). Minimizing the distance and drive time simultaneously comprises the main goal of this current research. In the present study, the regression model is the most suitable GIS model to identify the most significant factors affecting drive time.

Çela et al. (2013) used regression analysis to find the most significant variables related to road conditions, time of day and main causes affecting the high accident rates. The weaknesses of all the aforementioned research works lie in the fact that the problem of determining the fastest routes for distributing fresh vegetables was approached by adopting mathematical equations instead of GIS modeling. It is concluded that in the current study the volume of automobiles, distance of routes, population along the routes, two-way routes, presence of schools within 100 m, and residential units are the six explanatory variables used in regression analysis.

One study has offered the huge potential of biofilms for cleaning up hazardous waste sites, filtering municipal and industrial water and wastewater, and forming biobarriers to protect soil and groundwater from contamination Ashraf et al. (2013a,b,c).

The main issue about the environmental problem of waste dumping sites in Malaysia has the potential risk of groundwater pollution and its influence on surface water quality. The solid waste is usually disposed directly onto an unprotected natural soil formation Ashraf et al. (2013a,b,c).

Increasing the good quality food production requires the sustainable agriculture Ashraf et al. (2014). A good transportation system will help the delivery manager to send the production to the destination in the specific time.

A research was conducted on engineering classifications of tropical lowland peats. As mentioned in this research peats are considered to be partly decomposed biomass (vegetation). It is concluded that classification of peat for engineering purposes mainly involves the use of ignition test to determine the percentage of organic content Ashraf et al. (2013a,b,c).

3. Methodology

3.1. Location of study

The study area is Kuala Lumpur, and it encompasses producers of fresh vegetables as well as supermarkets as final delivery destinations together with road networks. The main fresh vegetable production area is a 5-hectare farm located in Seremban, an hour's drive from designated supermarkets and supermarkets in Kuala Lumpur. Figure 1 represents the map of the current study area (Figs. 2, 4 and 5).

In the above map on the right hand is the map of Malaysia and in the left hand is the Selangor state as the study area. The pink color is the location of production of the fresh vegetables. The main farmland of fresh vegetables is in this location. The main goal of this study is to improve the delivery services by selecting the least drive time routes. Therefore the transportation will start from this point to the city center. The Blue color is Kuala Lumpur city the main destination of fresh vegetables. Most of the supermarkets are located in this area.

The following figure shows a map of all the supermarkets in the KL district involved in this study, which form the destination points in all cases. The objective is to deliver goods to these designated locations based on customer demand.

3.2. Data collection

The first column of Table 1 details the spatial data, such as road networks, which are included in the base map. The road networks are collected in the form of spatial data from a GIS vendor. The task of such company is to digitize and produce different kinds of maps. From the perspective of land use, the map layers include market locations, residential areas, commercial areas, industrial areas, school zones, and population. Population is defined as the number of people living in a specific area, otherwise known as the population density in a particular area.

The non-spatial data consists of attributes that are complementary and related to the spatial data. In this regard, the factor comprising distribution cost is the drive time. Drive time includes several parameters, such as the specific travel distance and vehicle speed along the way.

The average speed of a vehicle moving along a road is affected by several parameters. Based on the results obtained from statistical analyses, the distance, land use, population,

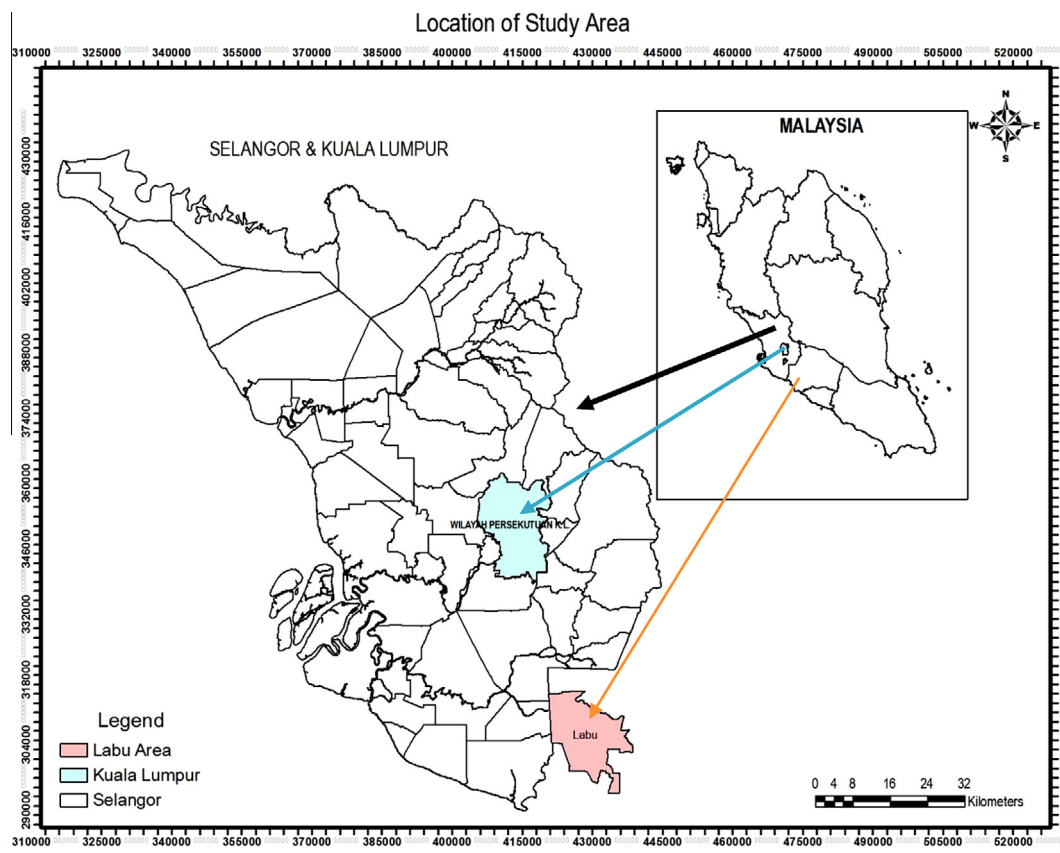


Figure 1 Study area.

car volume and school zones are variables that affect driving time. The following figure depicts all such variables when calculating the speed of a vehicle.

For the purpose of this research ArcGIS software is used for solving the problem of a complex network. ArcGIS software lets users explore and analyze the spatial data on their computers. Its basic mapping functionality and advanced GIS capabilities allow the user to create maps, showing the created maps, showing the data and integrate them and finally see the data in powerful new ways.

3.3. Model development

The initial development process for the spatial data contains information about the base map (digital map) as follows:

- (1) Road networks and transportation layer
- (2) Land use layers
- (3) Population

All these layers overlap each other and need to be accurately classified in order to prepare the data for analysis.

The next process step entails the preparation of the non-spatial data, which are made up of the following information:

- (1) The number and names of hypermarkets in the study location
- (2) The average speed for each route

- (3) Drive time
- (4) Car volume
- (5) Distance

After combining spatial and non-spatial data with the help of GIS technology, distribution management can be conducted and optimal routes based on the study requirements can then be selected.

The system development approach applied for this study and the group of procedures in general is presented in Figure 3.

3.4. Developing the database management system (DBMS) in ArcGIS

The first phase of the present study required using the GIS tool to build up a spatial database that contains detailed digital information about the routes in terms of time. This step involved setting up the attribute table by adding the variables identified in the methodology, which will be applied in the context of this study to create attribute tables for all the roads. First is the length factor, which represents the distance for each of the selected road networks. Preparing the results in this section required some calculations in ArcGIS software with geometry analysis. The information about distance for all the roads is derived from digitizing the road networks as spatial data set.

With the shortest time as the goal of route planning for delivery purposes, the impedance functions will be integrated

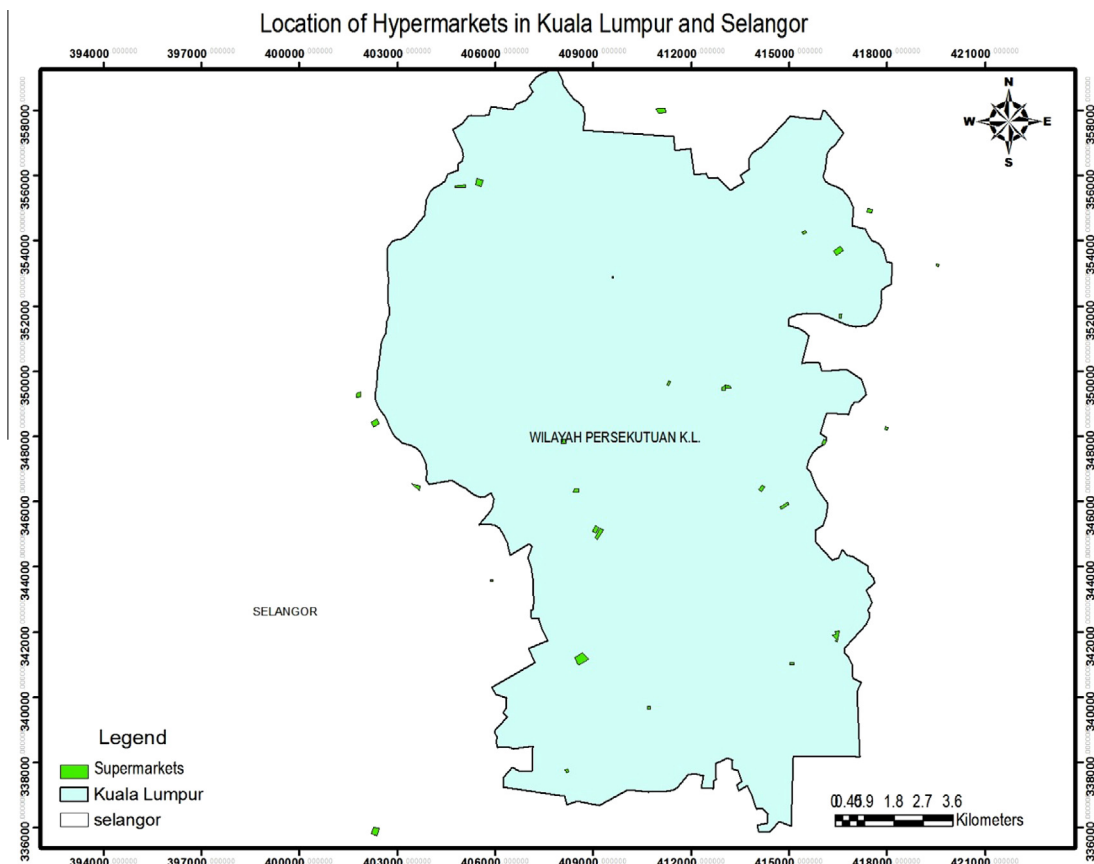


Figure 2 Map of hypermarket locations.

considering road length and the average speed of a transportation vehicle that affect driving efficiency (Dong and Shen, 2012).

In the current study, drive time is regarded as a dependent variable that facilitates deriving the most significant variables in the transport and delivery of fresh vegetables. Drive time plays an important role as a dependent variable, and through analysis, it is possible to determine the variables that are significantly altered in relation to the delivery of fresh products. In fact, the regression model is suitable and reliable for this research. This model requires predictions and it estimates time as a dependent variable to a number of independent variables.

To calculate drive time based on the average speed of a vehicle, the distance must be divided by the average speed of each vehicle. The travel times toward all destinations were determined by collecting data in accordance with different parameters. The results for drive time are in minutes, meaning the time that a vehicle will spend on a path from one point to another is also given in minutes. The calculation is based on the following formula (Eq. (1)) for further analysis.

$$[\text{Length}/\text{Average Speed}] * 60 \quad (1)$$

When time serves as a travel expense, there are some factors affecting travel time between origin and destination, such as school zones, traffic volume and one-way streets (Echols, 2003). The runtime of a vehicle is calculated by taking into account the length of the road and the speed of the vehicle on each road. All of the information regarding the average

speed of vehicle along the road networks in Kuala Lumpur was collected from the Ministry of Transportation and Traffic Management (DBKL).

Naturally, transport problems always occur as populations grow. Research by Chen et al. (2008) was done on nuclear waste transportation systems, whereby the population factor was applied in the work. In this study, the population parameter is classified based on the density of people living in one region. Weighted average will be used to combine a classified composite population. The weighted average method entails averaging two quantity variables and helps determine the relative importance of each quantity on the average. Weighting is the equivalent of having many similar items with the same values involved in the average. The data were sourced from the Department of Statistics, Malaysia.

The results were obtained from ArcGIS for the best routes based on the population class field according to attribute. Then the new network dataset was created for the new attribute table and impedance is the class field for population density.

Congestion has a straight relation with car volume and it causes the increase of drive time along roads. For this reason, the total car volume was calculated for each road and all the information on total car volume was gathered in one attribute table and saved in a specific attribute table. The main source of data was gathered from the Ministry of Transportation and Traffic Management (DBKL).

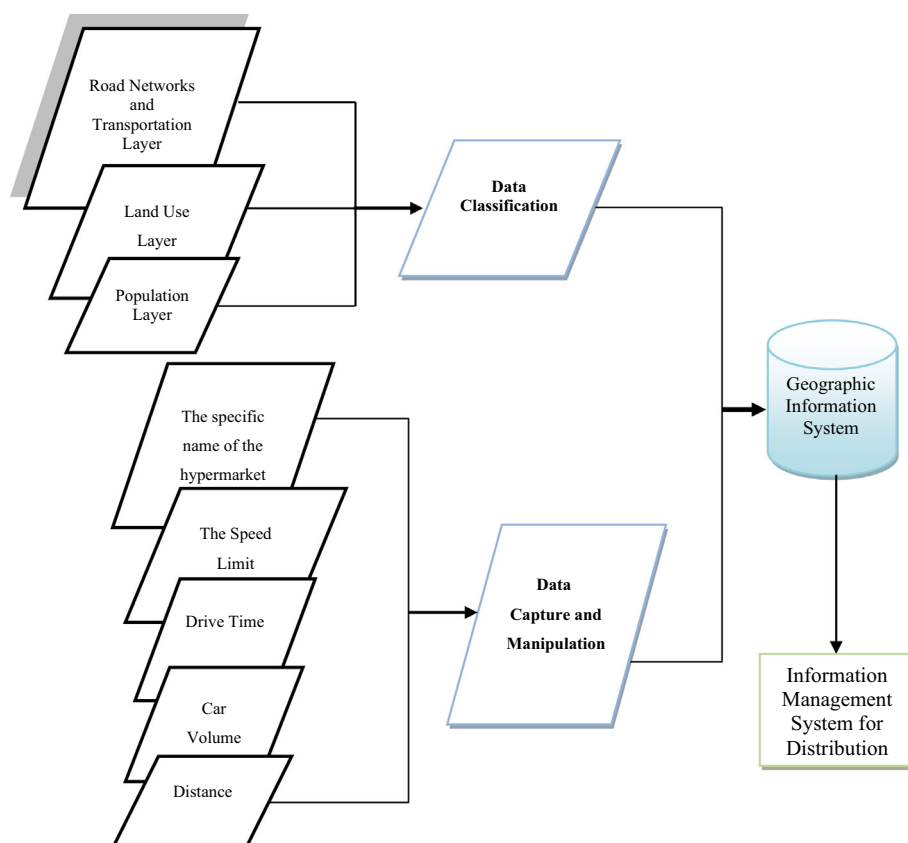


Figure 3 Conceptual framework.

It has been discovered that the land use characteristics in transportation and delivery services affect vehicle drive time on a road. The results obtained from the land use classification are a land use map of the study area. This land use map was categorized into three classes, namely residential areas, industrial areas and open spaces. The different land use classes served to differentiate the various terrains over the study area, and they were used in the final decision-making of the best alternative paths. These data were collected from the Department of Land Use and Cartography in KL.

Another parameter affecting the delivery time of fresh vegetables during transport is the location of schools on the map. This step involved the identification of all schools on a digital map of KL. Locating schools allows the creation of a 100 m buffer zone from the main roads network, as the average speed on these types of roads is usually 35 km per hour.

4. Results of statistical analysis

One of the reasons for adopting the regression model in this study is that it provides decision makers with a powerful set of tools, which allows prediction regarding present or future events via the accumulation of knowledge of past and present events.

The regression model in Eq. (2) includes the width from the origin (fixed coefficient) and coefficients of 8 independent variables. $C(i)$ indicates the coefficients of independent variables; $LTIME$ is the log of drive time as a dependent variable; and $LLENGTH$ and $LPOP$ indicate the log of distance for each road network and log of population in a specific area, respec-

tively. The proposed hypotheses have been designed on the basis that each coefficient in the regression model is significant.

$$LTIME = C(1) * CARVOLUME + C(2) * LLENGTH + C(3) * LPOP + C(4) * TWOWAY + C(5) * SCHOOL + C(6) * RESIDENTIAL + C(7) * INDUSTRIAL + C(8) * OPENSOURCE + C(9) \quad (2)$$

4.1. Final regression model

The following model in the regression analysis (Eq. (3)) is the final equation that contributes to this research. The most significant parameters affecting drive time are identified using the following formula.

$$LTIME = +0.2663 * CARVOLUME + 0.6984 * LLENGTH + 0.0203 * LPOP + 0.0605 * TWOWAY + 0.1681 * SCHOOL + 0.0317 * RESIDENTIAL - 0.5497 \quad (3)$$

The results obtained from this regression analysis are shown in Table 2.

4.2. Statistical results

- (1) Based on the coefficient obtained for volume of cars, a 1% increase in the volume of vehicles on the investigated routes will cause a 26% increase in the period required to transport the products.

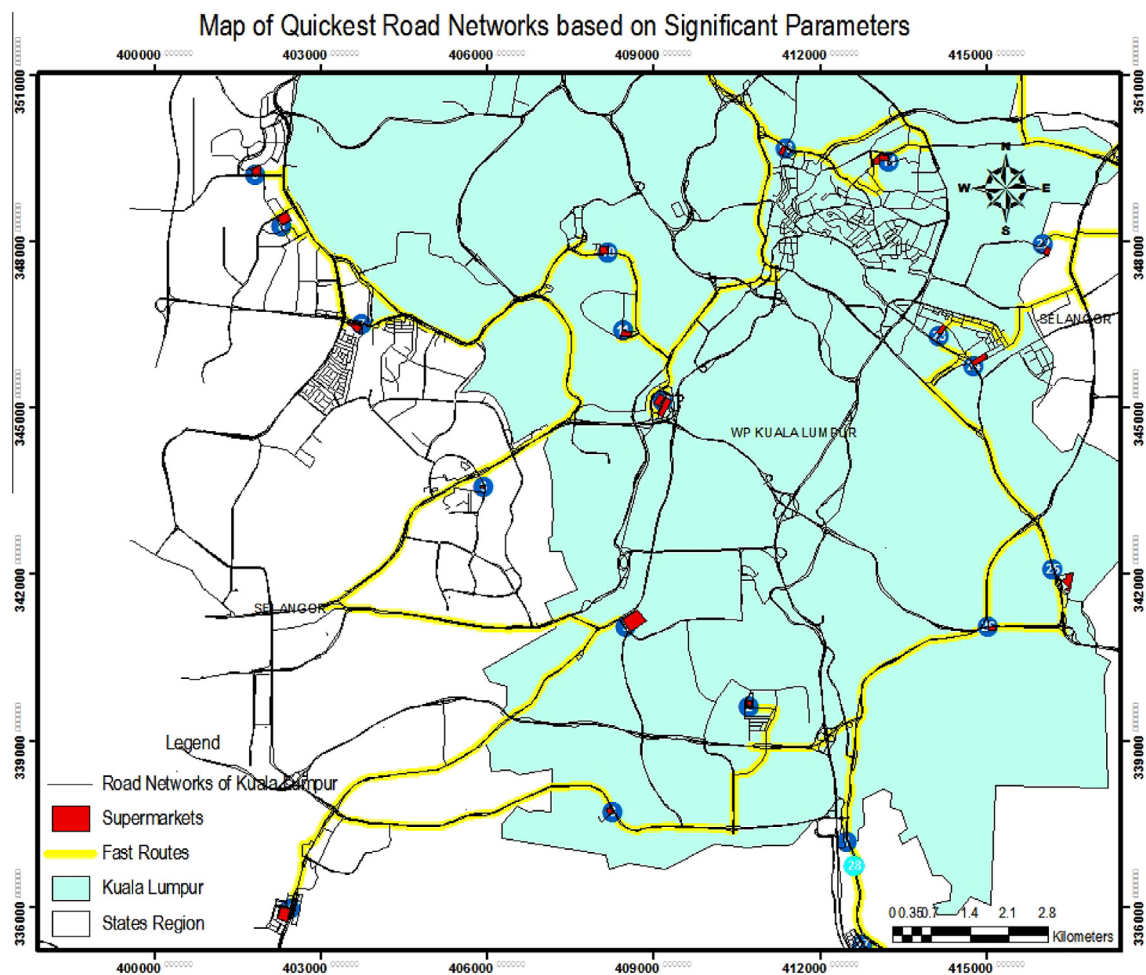


Figure 4 Map of fast routes based on all tested variables.

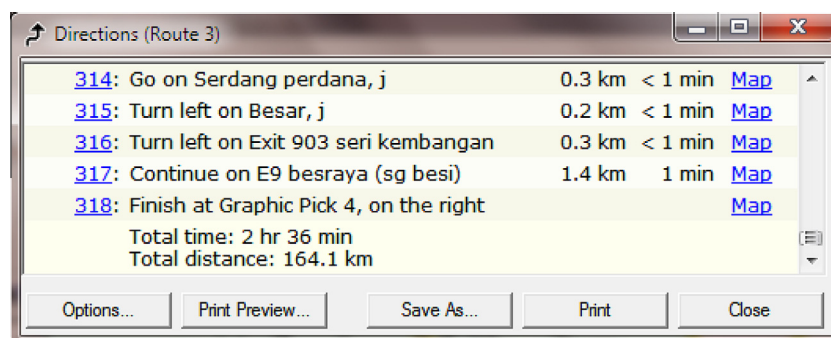


Figure 5 Total time and distance for selected routes based on all variables.

- (2) The traveled distance variable similarly has an increasing effect according to the research prediction. Based on the coefficient of this variable, a 1% increase in the traveled distance will cause a 70% increase in the necessary time to transport the products.
- (3) Moreover, the population variable has shown a 2% increase in the necessary time for delivery.
- (4) Another explanatory variable is the existence of schools within 100 m from transmission routes. The positive and significant coefficient obtained for this variable indicates that the presence of schools near transmission routes causes a 16% increase in transport time.
- (5) The virtual variable of residential zones is also effective and significant, such that if the product delivery route is a residential unit, it will increase delivery time by up to 3%.

Table 1 Types of data for GIS analysis.

No.	Type of data	
	Spatial data (Feature)	Non-spatial data (Theme)
1.	Base Map <ul style="list-style-type: none"> ● Road Networks 	Length of Drive Time includes: <ul style="list-style-type: none"> ● The specific travel distance between the certain places ● The average speed along the routes and also considering speed limit ● Drive time ● Car volume
2.	Land use Map <ul style="list-style-type: none"> ● Market location ● Residential Area ● Commercial Area ● Population ● School zone ● Industrial Area 	The name of markets for the specific location

- (6) After evaluating the land use data in the statistical process, running the regression model and identifying the output, the residential area seems to be the most significant factor affecting drive time on related roads. Therefore, the emphasis of this research is on residential areas.

5. Discussions

The most significant variable among all variables in the final regression analysis is distance. The coefficient of distance, which was obtained from the formula, is 0.6984. It means that distance has the most impact among all variables on drive time.

The second one is car volume in terms of higher coefficient obtained in the regression analysis. The coefficient obtained in this regard is 0.2663.

The third one is the school zones, which the coefficient obtained for this variable is 0.1681.

Forth one is two-way restriction. The coefficient obtained for this kind of variable is 0.0605.

Fifth one is residential areas. The coefficient obtained for residential area is 0.0317.

Sixth one and the last parameter is population density and the coefficient obtained for this variable is 0.0203.

The population has the lowest coefficient obtained among all the variables and has the lowest impact on drive time.

5.1. GIS model discussions

Map is based on ideas such as layers; projection, generalization, and symbolization which are still prevalent in GIS and account for a large proportion of the capabilities in GIS (Goodchild et al., 2007).

Considering shortest time as the goal of route planning for delivery purpose, the impedance functions will be integrated considering the length of the road and average speed of a transportation vehicle that affect the driving efficiency (Dong and Shen, 2012). The length and speed are the most important indicators of travel time in urban transportation system. The shortest link length, the faster sections of speed, causes the shorter travel time (Dong and Shen, 2012).

Table 2 Regression model results.

Variable	Coefficient	t-Statistic	Prob.
Dependent variable: LTIME			
Method: least squares			
CARVOLUME	0.2663	2.9740	0.0030
LLENGTH	0.6984	8.1765	0.0000
LPOP	0.0203	2.1327	0.0333
TWOWAY	0.0605	3.4513	0.0006
SCHOOL	0.1681	5.9863	0.0000
RESIDENTIAL	0.0317	2.5219	0.0119
C	−0.5497	−0.4730	0.6363
Regression statistics			
F-statistic	7058.5	Adjusted R-squared	0.986718
Prob (F-statistic)	0.0000	Durbin-Watson stat	1.3539

The vehicle routing process will find the quickest routes. For the routing process, the street data must have a field that saves a value, which relates how much time is needed to pass through each street. In this case, the impedance is time, which frames the quickest route as the best route. Hence, the best routes can be defined as the route that has the lowest impedance or lower cost, where the impedance is selected by the user.

The following figure describes the best routes when it is going to distribute to requested hypermarkets around the city.

The main contribution about this study is that to find out the parameters involving in transportation problem in terms of drive time. This study finds out those parameters and takes to the consideration of finding the best routes by GIS software.

The following figure depicts the best routes after considering the combination of all variables on road networks. The average drive time is calculated by dividing the speed of the vehicle by the traveled distance. The average speed of a vehicle is affected by several parameters that have been discussed in the methodology section. It is concluded that the volume of automobiles, distance of routes, population along the routes, two-way routes, presence of schools within 100 meters, and residential units are the six explanatory variables of the time variation observed during the transportation of fresh products.

The subsequent figure provides information on the total distance and total time of selected routes for the delivery of fresh vegetables, taking into account one-way roads. The analysis is done using the results obtained from the attribute table according to the average speed of a vehicle in ArcGIS to selected hypermarkets in the city center. The total time and total distance of 2:09 h and 86.4 km, respectively that a vehicle must travel along roads to reach the destinations are shown in the next figure. The final destinations, or hypermarkets, are selected by delivery managers based on the respective demands from hypermarkets.

The results obtained from the regression model show distance for the delivery routes having a positive effect on the delivery time of vegetables. The main purpose of using this method is that the routes should be chosen to minimize the total distribution cost.

6. Conclusions

It has been realized that sometimes, the shortest distance could not provide the best solutions, due to extended time consumptions that are caused by traffic conditions during the way.

Some streets can show passes in both directions, while others only one. It also needs to take into consideration the one-way roads. Restrictions are identified for particular features, so during an analysis, restricted objects cannot be traversed.

Route directions are forced to discover the optimal routing to visit the requested hypermarkets, based on their demands in their own directions.

After identifying the key factors for determining the optimal path in terms of time, the Database management system will then be implemented. For this study, DBMS is essential in the application where large amounts of GIS data need to be maintained and managed.

GIS can both model transportation networks, and integrate the association of network characteristics directly into a database. In this regard, finding the fast routes for the delivery of fresh vegetables takes into account different parameters as its impedance.

Current research concentrates on the GIS tool to solve the distribution problem via the utilization of the Network analyst tool. This tool helps the decision-makers determine the best routes among all of the existing road networks for transportation and delivery services.

The regression model is the most proper model for this kind of research, and the variables that have been mentioned in literature review are tested via this model.

In this research it was demonstrated how GIS is applied in order to obtain the best calculation results to derive the fastest delivery service routes. This paper presented the implementation of statistical analysis using a regression model to identify the key factors affecting driving time. The regression model can provide information needed to estimate the values of a dependent variable when the independent variables' values are known and there is a relationship between the two variables. The regression model used in this study was explained, followed by the identification of variables as key factors in modeling that aid with the decision-making process for transportation planning.

The main findings of this research are that, the volume of automobiles, the distance of routes, the population in the routes, two-way route, and the existence of a residential unit are the five explanatory variables of the time variation that were observed during the transportation of fresh products.

It is recognized that the shortest distance does not always provide the best solution due to extra time consumed as a result of traffic conditions along the way. Moreover this research demonstrated how a decision maker should choose the best routes to deliver fresh vegetables based on the criteria and constraints presented in this research. Network analysis helps users identify the shortest distances, and simultaneously the fastest routes from markets, and also provides information about road directions based on data collected in the attribute table via different types of maps. The advantage of this research is that focus was directed toward the use of spatial data to provide visualization output by producing several maps and analyzing the results.

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